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TH32 - Improving Realism in Fire Probabilistic Risk Assessments

Experimental Studies of High Energy Arcing Fault (HEAF) by S/NRA/R

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1. Background

A High Energy Arcing Fault (HEAF) occurred in the high-voltage (6,900V) metalclad switchgear (M/C) at Unit 1 of Onagawa Nuclear Power Station (NPS) of the Tohoku Electric Power Company Co., Inc. on March 11, 2011 due to the 2011 off the Pacific coast of Tohoku Earthquake.

(http://warp.da.ndl.go.jp/info:ndljp/pid/9483636/www.nsr.go.jp/archive/nisa/earthquake/files/houkoku230530-2.pdf)

HEAF events, although their impacts differ each other, have occurred in the electrical equipment and components in the NPSs worldwide. Efforts are being taken to understand the phenomena and to develop evaluation methods.

2. Objectives of HEAF tests

- To understand the basic characteristics and behavior of HEAF
- To understand what occurred in the Onagawa NPS Unit 1 due to HEAF event during the 2011 off the Pacific coast of Tohoku Earthquake

---------- (In the future) ----------

- Develop regulatory guidance for Fire Hazards Analysis Methods for HEAF
  - Models for damage predictions and setting Zone of Influence (ZOI)
  - Methods for the Protection against HEAF

3. S/NRA/R HEAF tests

S/NRA/R HEAF Tests

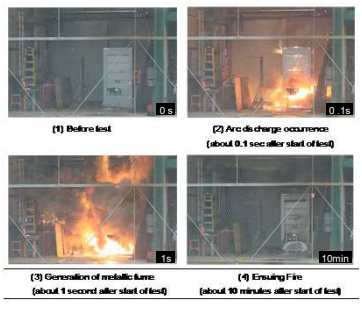
Collaboration with
NRC
NIST
KEMA

- Low Voltage HEAF Tests
  - Distribution Panel (DP)
  - Motor Control Center (MCC)
- Onagawa Configuration Tests
  - Metalclad Switchgear (M/C) 5-cabinet lineup

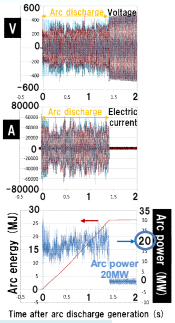
5-cabinet lineup
Heat source: Rocket fuel
Burned test

Distribution Panel (DP)	Motor Control Center (MCC)	Metalclad Switchgear (M/C)
Voltage : 480V (Set point) Current : 52.3kA (Target value)	Voltage : 480V (Set point) Current : 63.5kA (Target value)	Voltage : 7000V or 7100V (Set point) Current : 22.6kA - 25.0kA (Target value)
Arc discharge Duration: 2s HEAF tests: 3 times	Arc discharge Duration: 2s HEAF tests: 4 times	Arc discharge Duration: 1s, 2s, 2.5s, 3s HEAF tests 6 times

4.1 S/NRA/R HEAF test results <Distribution Panel>

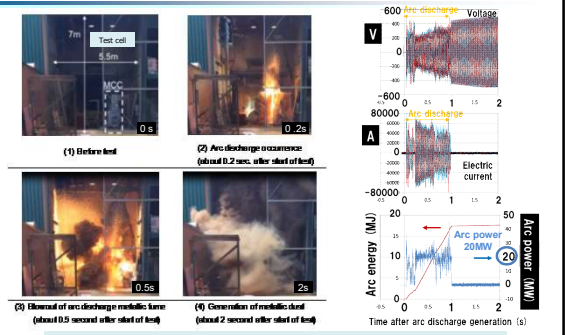


(1) Before test
(2) Arc discharge occurrence (about 0.1 sec after start of test)
(3) Generation of metallic fume (about 1 second after start of test)
(4) Ensuing Fire (about 10 minutes after start of test)



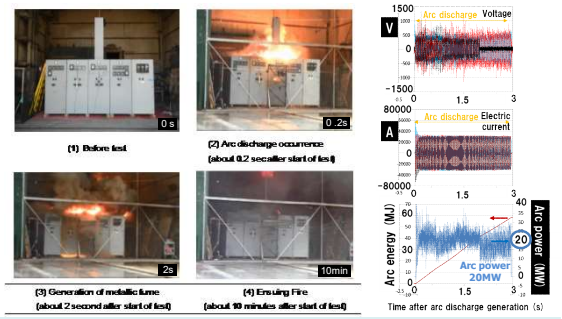
In the DP HEAF tests, ensuing fire occurred in two out of three tests.
Arc power was approximately 20MW for all the tests.

4.2 S/NRA/R HEAF test results <Motor Control Center>



In the MCC HEAF test, the ensuing fire did not occur for all four tests.
Arc power was approximately 20MW for all tests.

4.3 S/NRA/R HEAF test results <Metalclad Switchgear>



In the M/C HEAF tests, ensuing fire occurred in four out of six tests.
Arc power was approximately 20MW for four tests and larger than 20MW for two tests.

5.1 Discussion topics <Arc power>

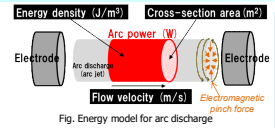


Fig. Energy model for arc discharge

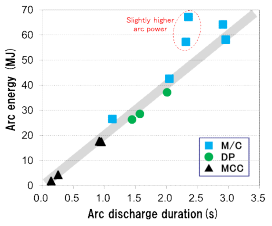


Fig. Relationship between arc discharge duration and arc energy

- Proportional relationship is confirmed between the arc energy and the arc duration for each electric cabinet, and the arc power is almost constant.
  - The arc power is a value multiplied by an **energy density**, a **flow velocity** and a **cross-sectional area** of arc jet.
  - Two key factors;
    - Saturation phenomena of **energy density**
    - Inverse relationship between **flow velocity** and **cross-sectional area**.
- Two data with slightly higher arc power were obtained. It needs further consideration.

5.2 Discussion topics <Ensuing fire>

- S/NRA/R HEAF tests showed that the arc energy required for initiating ensuing fire differed between distribution panels and metalclad switchgears.
  - The values of arc energy which can cause ensuing fire were between 26.3 and 28.6 MJ for the distribution panels and between 42.6 and 57.2 MJ for the metalclad switchgears.
  - Values of arc energy required for causing ensuing fire were obtained. This triggering energy is considered to be dependent on the characteristics of individual electric cabinets such as interior volume and ventilation opening area.

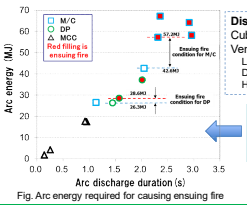


Fig. Arc energy required for causing ensuing fire

Distribution Panel
Cubicle size: **Middle**
Ventilation opening area: **Middle**
Length: 0.9 m
Depth: 1.2 m
Height: 2.3 m

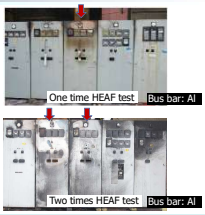
Metalclad Switchgears
Cubicle size: **Large**
Ventilation opening area: **Large**
Length: 2.1 m
Depth: 0.9 m
Height: 2.3 m

If arc discharge duration could be reduced, arc energy would be decreased and consequently ensuing fire could be prevented.

5.3 Discussion topics <Onagawa HEAF event>

(http://warp.da.ndl.go.jp/info:ndljp/pid/9483636/www.nsr.go.jp/archive/nisa/earthquake/files/houkoku230530-2.pdf)

HEAF event at Onagawa NPS Unit 1, it is supposed from observation of the damage condition that the arc discharge was occurred two times in the different Metalclad switchgears.



- The damage of metalclad switchgears at Onagawa NPS Unit 1 was more severe than that after HEAF tests.
  - Aluminum bus bars of the metalclad switchgears at Onagawa NPS Unit 1 were severely damaged compared with those of HEAF tests.
  - Burning (oxidation) of the bus bar made of aluminum can cause huge heat energy release by oxidation of aluminum. Therefore, in addition to the arc energy due to HEAF, the high energy of aluminum bus bar oxidation should be considered in the consequence evaluation for HEAF events in electric cabinets.

6. Summary

- HEAF tests were conducted to obtain the insights about progress of HEAF events, energy level of arcs and condition for ensuing fire. Based on the test results, an energy model of arc discharge has been studied.
  - For various electric cabinets, insights of event progress were obtained pertaining to generation and leakage of arcs, generation of metal fume and ensuing fire.
  - Proportional relationship was observed between arc energy and arc duration irrespective of types of electric cabinets for all cases.
  - Values of arc energy required to cause ensuing fire were obtained. This triggering energy is considered to be dependent on the characteristics of individual electric cabinets such as interior volume and ventilation opening area.

Thank you for your attention!!